

2005-06-01

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Recommended Citation

Kennedy, D., Brosnan, D.: Manufacture of near net shaped 3-dimensional components for industrial applications. International Conference on Materials, Tribology and Processing, MATRIB M. Grilec (ed). Coatia, 23-25 June, 2005.

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Manufacture of Near Net Shaped 3-Dimensional components for Industrial Applications

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Abstract

The development of near net shape 3-Dimensional products for industrial applications has been one main goal for Manufacturing Industries over the last few decades. Processes such as polymer blow moulding and its various stages of development, glass forming, extrusion, forging, centrifugal and sand casting, bulge forming and vacuum forming are typical processes that have contributed to this development. Current practices centre on Surface coatings, Rapid Prototyping, laser forming and nanotechnology manufacture of complex 3-D shapes and assemblies.

The work described in this paper is a new and highly efficient and cost effective technique for producing 3-Dimensional thin walled shapes by using compressed gases to form and shape molten materials in a mould or die. A number of rectangular and cylindrical shapes have been produced to prove the concept and it proves to be successful in manufacturing near net shaped 3-D components of industrial standard.

1. Introduction

Numerous methods of producing near net shapes from raw materials have been developed over the years. Raw Materials of glass, plastics and metals are been formed by complex processes which include glass blowing, polymer blow moulding and some casting techniques for raw metals.

In glass forming, such as bottle making, the molten glass is formed in a mould by the aid of air pressure, and the semi molten glass takes up the shape of the desired mould. Any waste is removed by cutting or grinding. For more delicate and craft type work, the glass is shaped by expert blowers and cut to specified patterns and designs before completion. Advances in this craft area has seen the introduction of Computer Numerically Controlled equipment to machine the patterns into the glass, thus speeding up the process and eliminating the craft work from the process.

Mass production of polymer components has from its inception, been high volume and almost perfect near net shape 3-dimensional construction. Materials development and novel manufacturing methods are a core activity of Engineering, especially in relation to developing strong collaborations with industries and SME's, and new company start ups.

Presented here is a novel method which will seek to gain the most optimum way of shaping materials at minimum costs to near net shape and will provide valuable research and development information to apply the process to industrial applications.

2. Near Net shape Manufacturing Processes:

Some manufacturing techniques for producing near net shapes such as hollow cylindrical sections have been in existence for over a century. These include processes such as centrifugal casting and sand casting using internal cores to make a hollow shell. Typical products made from these techniques include pump casings, engine casings and tubular pipes. Processes such as extrusion, forging, fabrication and complex machining techniques are also in use whereby raw materials are shaped from solid stock or from metal sheets. Normally the manufacturing process will be determined by the type of materials used, the costs involved and the skills available. Other established processes are glass blowing of glassware components and products. More recently, bulge forming processes have been developed to re shape tubular sections for new applications.

The application of compressed air to forming polymeric materials is well established and the most common application involves blow moulding for manufacturing plastic containers from vehicle fuel tanks to simple containers and bottles. Advances in producing near net 3-dimensional shapes from raw materials have been developed over the past decades. These include injection moulding, extrusions, casting and centrifugal casting, rotational blow moulding, vacuum forming, and more recently, rapid prototyping which is a generic term for a wide range of forming processes from polymers and metals, on a layered basis.

In order to decide if a product can be made in one or more parts, the following needs to be defined as outlined by Boothroyd and Dewhurst [1].

- i. does a part have to move relative to adjacent parts?
- ii. does a part have to be made of a different material to other parts, and
- iii. should it be separate to allow for assembly of other parts.

Designing components for ease of manufacture is not necessary today due to the sophisticated machinery and technology available. Even parts that move relative to other parts such as a spring can be incorporated into adjacent components through the use of advanced manufacturing technology and modern engineering materials. This means products that once consisted of a number of parts can be made in one piece. This is shown in Figure 1. which is a polymer part for a food mixing machine. It consists of one single part that was initially made from 20 pieces including small springs, nuts, bolts and washers. The spring is now part of the product. Designs emerging from such processes are quality in nature and easier to produce, therefore reducing time to market. 3-D manufacturing should be fully utilised to improve production, improve tolerances and reduce costs.

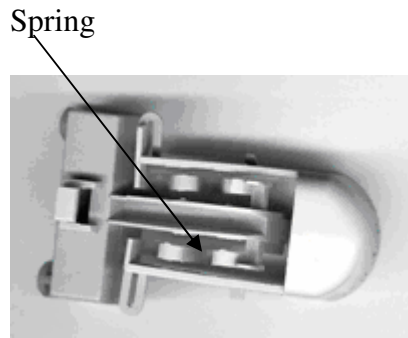


Figure 1. Complex designs and manufacture of multiple functions into one product.

Figure 2. shows elastomeric and metallic components, mass produced for use in the automobile industry. The polymer components are injected moulded at high speeds by an expensive tooling and manufacturing process while the crank shaft is manufactured by a forging process to near net shape and then finish machined.

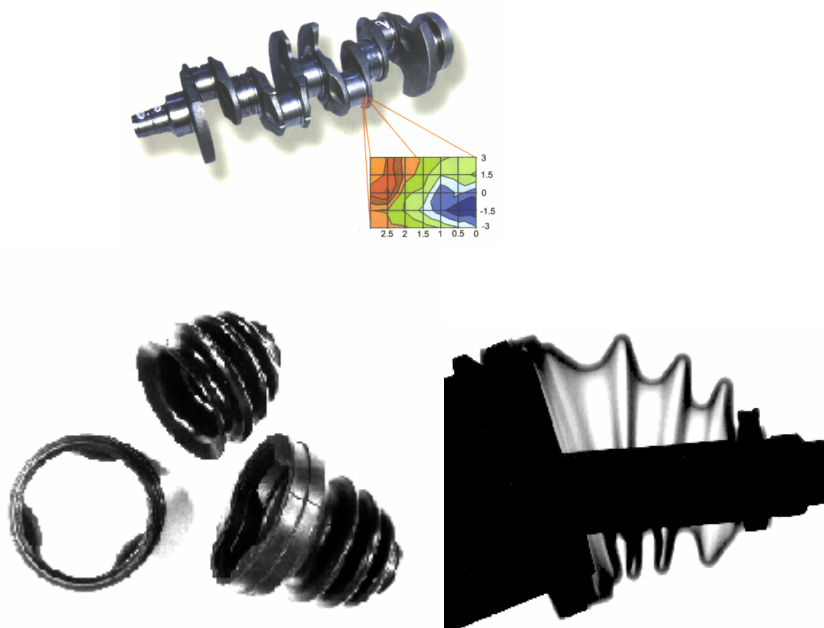


Figure 2. Net shape components for the automobile industry.

Figure 3. shows a basic but typical method of manufacturing a component for a particular application. In this design, eight parts are associated with the product, four bolts, one base, two uprights and a machined cross bar. This product through further research and development can be reduced down to two parts.

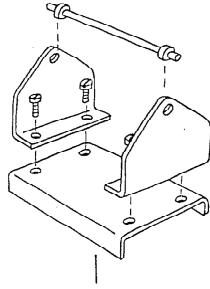


Figure 3. Multi part assemble.

3. Air Forming Process

Air forming of components is a new method (developed by the primary author) of producing cylindrical and hollow metallic parts to near net shape using compressed air. It consists of injecting and directing compressed air into a mould containing a molten material. Under air pressure, the molten material will take the shape of the internal mould and also create an internal cavity in the product. This process is similar to glass forming where glass blowers “blow” air into semi molten glass through a tube, thus creating a hollow cylindrical shape. The wall thickness of the components can be controlled by utilising the correct air pressure and volume. The variable that determine the quality and shape of the components include:

- i. material cooling rates.
- ii. gas pressure employed
- iii. gas velocity and volume
- iv. compressed gas direction.
- v. type of compressed gas used (standard air or inert gas).

The main advantage of the process includes the speed of forming, low cost of forming and elimination of the need for an internal core. This can have significant labour savings and reduce the time to market. The process is highly advantageous to decorative castings and artwork such as statues, busts, and castings requiring low strength properties. Of particular use is in the casting of pump and motor casings and housings. A broad range of engineering materials can be used in this process. Innovative methods of manufacturing products in a cost effective and efficient manner forms the main theme of this research work.

The research work proposed here involved producing near net shape hollow-section components by applying compressed air or gas to casting technology.

By pouring molten material into preformed moulds and simultaneously injecting compressed air from the base or top of the mould, a hollow component can be produced. The molten materials will take the shape of the internal mould wall and the compressed air will create an internal cavity. The size and shape of this cavity will be determined by the air pressure and air flow rate employed at the time, producing 3-D objects to a variety of shapes, based on the internal mould design.

Initial studies and tests on a 350mm by 60mm by 50mm rectangular shaped mould have shown some basic but promising results. The main advantage of this technique is that it can form complex shapes and it can be applied to a broad range of metals and alloys, especially those that are difficult to machine. It also represents a low cost, rapid manufacturing process over conventional methods and produce components to near net shape.

From initial tests conducted at the Faculty of Engineering at DIT Bolton Street, the process was optimised in terms of air pressure and volume and this will now klead to industrial collaboration. These industries will include casting companies, pressure die casting organizations and companies involved in extrusion processes.

The research work focused on forming shapes from different alloys and metals and developing greater complexity in shapes.

The stages in the air forming process are shown in Figure 4.

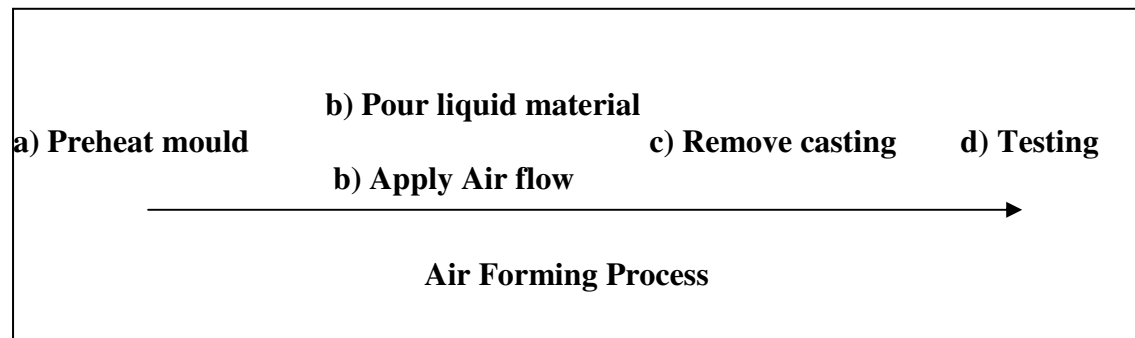


Figure 4. Air Forming Process

4. Results of Air forming Process

Initially a simple tapered mould was produced from steel. This contained an air pipe as shown in Figure 5. On pouring the molten material into the preheated mould, the air pressure through the air pipe was increased until such time as the pressure was adequate to force the molten material to rise up the mould wall and take the shape of the mould cavity. The mould was preheated to approximately 200 degrees Celsius in a simple tempering oven prior to pouring. The molten material was forced by air pressure to completely cover the internal surface of the mould.

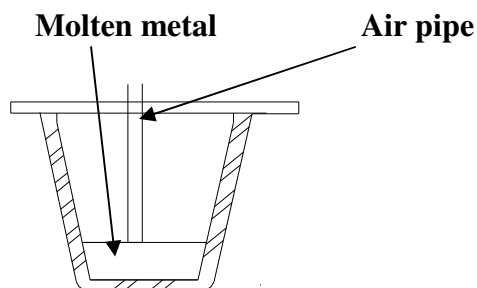


Figure 5. Air Forming Mould

Figure 6 shows the initial test conducted on molten aluminium in a steel cavity using an air pressure of 2.5 Bar. This high pressure produced a 400mm high cylindrical vessel of cross section shown in the figure. Figure 7. shows the external surface of the formed casting. Figure 8. shows the wall thickness of a simple cavity produced by the air forming process. The thick base is an indication that air pressure was not adequate to produce a uniform wall thickness around the surface of the mould. It is noticeable that at the top part of the casting, the wall thickness is uniform and in the order of 0.5mm in thickness. This thickness was repeated on a number of samples produced during the experimentation phase of the work and verifies that the process works effectively with the correct air pressure and air volumes employed.

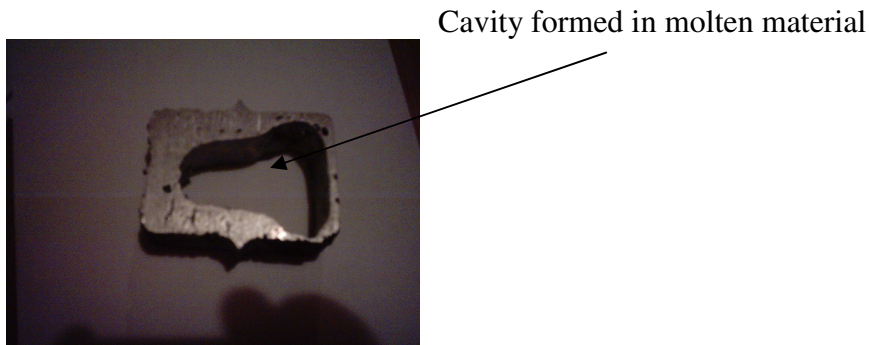


Figure 6. 65mm X 45mm cross section air formed aluminium sample.



Figure 7. External wall of air formed product

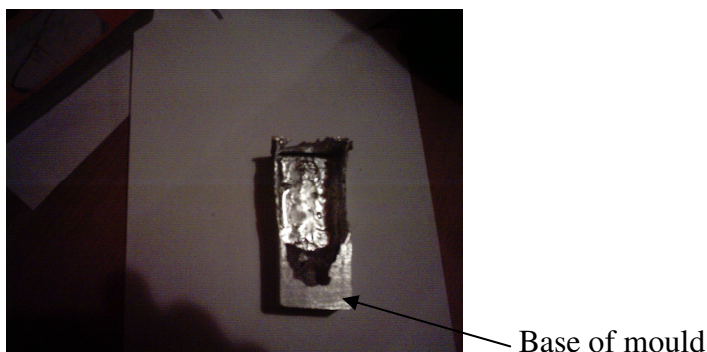


Figure 8. Cavity produced by air forming process

5. Conclusions

The research work proposed here incorporates a new approach to product manufacture and has relevance to a wide range of manufacturing industries involved with castings, injection moulding, tooling, extrusions and 3-D forming.

The main research aspects to this project include the design and manufacture of suitable moulds to investigate the feasibility of producing near net shape components by air forming molten metals. The application of different gases, air pressures and air volume along with air direction have improved the initial tests undertaken. The level of porosity produced in the air forming process will be of major interest to manufacturing processes. The material types suitable for this process including noble, exotic alloys and traditional metals. Future work will concentrate on mathematical modelling using different air pressures, flow rates and material densities in relation to the mould size to produce different wall thicknesses.

This project will lead to the development of a new manufacturing process for producing hollow components that are currently made by other methods. The applications to mechanical/manufacturing industries in Ireland and abroad are significant and the forming technique proposed will offer an economic and cost effective method of production over other processes.

A product's basic design determines how it is made and what it will cost to produce.

A suitable design process takes account of manufacture, assembly and materials to improve product quality, reduce costs and time to market. Almost 80 to 90% of the product quality and cost are determined at the design stage and not at the manufacturing stage, yet only 5% or less of the costs are invested in design. As this process is a relatively simple one to control, changes are easier to make and therefore quality and manufacturing parameters can be optimised.

References

- [1] G. Boothroyd & P. Dewhurst, Less is more, more or less, Manufacturing Engineer, November 1989.